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EXPLORATORY STUDIES ON THE DESIGN OF ACOUSTIC SPLITTERS FOR WIND TUNNELS

by

W. J. G. Trebble   A071433

January 1980

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EXPLORATORY STUDIES ON THE DESIGN OF ACOUSTIC SPLITTERS FOR WIND TUNNELS.

by

(10)   W. J. G. Trebble

SUMMARY

This Memorandum discusses the choice of geometry and materials for acoustic
splitters in wind tunnels, with particular reference to the requirements for
modifying the 5ft and 24ft tunnels at RAE. The optimum theoretical design of
acoustic splitters is considered first and then practical materials to match the
requirements are chosen. Experimental investigations at small scale in an aero-
acoustic research rig with ducted flow are described. Attention is drawn to the
need for the splitters to have a good aerodynamic profile and to the problems
associated with the self-noise of the splitters when they are installed in high-
speed sections of the tunnel circuit.

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LIST OF CONTENTS

1   <u>INTRODUCTION</u>

Noise research has been conducted in the 24ft tunnel at RAE with simulated forward flight since 1970 but limitations on the maximum usable airspeed have been imposed by the background noise levels of the facility[1]. A pilot study was started in the 5ft wind-tunnel[2], which was a scale model of the 24ft tunnel, to examine the possibility of improving the aero-acoustic performance of the larger tunnel by circuit modification. In both these tunnels (Fig 1) the fan was installed in the collector close to the test-section, with the result that rather high noise levels occurred in the working-chamber, both inside and outside the airstream. As an indication of the limitations that must be placed on the airspeed for noise research a comparison is given in Fig 2 of the noise spectra typical of a 20mm diameter jet nozzle and for the background noise of the original 5ft tunnel. Modifications to the circuit (Fig 3) were based on the assumption that the fan would be moved to a position between the second and third corners of the return circuit, to permit the installation of acoustic absorber splitters both upstream and downstream of the fan.

This Memorandum describes the exploratory studies which led to the choice of geometry and materials for acoustic splitters in the recommended design modifications to the 5ft and 24ft tunnels. Subsequently the design modifications were adopted when the smaller tunnel was modified into the 1.5 metre acoustic-tunnel[2].

2   <u>THEORETICAL DESIGN OF ACOUSTIC SPLITTERS</u>

The acoustic splitters have been designed using the theory of Cremer as reported by Beranek[4], which applies to blankets of acoustically absorbent material mounted parallel to the axis of a duct. The splitters are considered to be made from homogeneous porous material and, following studies by Delany and Bazley[5] at the NPL, the acoustic impedance for such materials is expressed as a unique function of their flow resistance. For this theoretical treatment, the important physical parameters of the splitter design are taken to be:

Splitter length	$= \ell$ (mm)
Splitter thickness	$= 2t$ (mm)
Air gap between splitters	$= 2h$ (mm)
Flow resistance of absorbent material in splitters	$= R_1$ (mks rayls/m) .

It can then be deduced from the work of Cremer that the peak attenuation occurs at a frequency

$$f_0 = \frac{101.6}{\sqrt{ht}} \quad \text{(kHz)}$$

and the maximum level of noise attenuation at this frequency then occurs if the blanket material has a flow resistance

$$R_1(\text{opt}) = 66.75 \sqrt{\frac{h}{t^3}} \times 10^4 \quad \text{mks rayls/m} \quad .$$

Fig 4 shows the effect of variations in the dimensions of the splitter design on the frequency at which peak attenuation is predicted, together with the appropriate flow resistance for the blanket to give optimum performance at that frequency. For example, with splitters of 50 mm thickness, peak attenuation at 2.5 kHz would require air gaps of 132 mm between splitters and the blanket should have a flow resistance of 4.3×10^4 rayls/m. Having fixed the splitter design, the theory may then be used to determine the noise attenuation spectra over a range of frequencies.

Such a sharply-optimised design would limit sound attenuation to a rather narrow band of frequencies but, as shown in Fig 5, this frequency band can be increased if material with a higher flow resistance is chosen for the acoustic blanket, though this is at the expense of a somewhat lower level for the peak attenuation. For wind-tunnel applications, the best overall attenuation would appear to require a material with a flow resistance some $1\frac{1}{2}$ to 2 times the value of R_1 indicated in Fig 4.

Some account must be taken of the need for good aerodynamic performance of the tunnel before proceeding further with the splitter design. Acoustic considerations on their own would probably result in the design of thick rectangular splitters of maximum length, but aerodynamic considerations imply that the splitters should be of a low-drag shape in order to minimise the pressure loss in the circuit. Semi-elliptic noses and tapered tails should therefore be included in the splitter profile. Space limitations in the first leg of the 5ft tunnel limited the overall splitter length to 1.5 metres. The thickness of the splitters are therefore limited to 50 mm by the requirement that the tapered tails should not exceed 0.5 metre in length with a thickness to length ratio of not more than 0.1. In the 24ft tunnel, where splitters can be nearly five times as long as in the 5ft tunnel, the corresponding thickness would be 240 mm.

_____Although the profile of the individual splitters was determined by aero-
dynamic considerations, this still left some freedom of choice in selecting the
number of splitters to be fitted at each of the two stations in the tunnel
circuit; at each station the tunnel width is 1.9 metres. Increasing the number
of splitters (Fig 6) would achieve better acoustic performance, though at a
higher frequency, since the air gap between splitters would then be reduced. On
the other hand, the air speed through the splitter passages would increase with
the reduction in free air area and there would also be significant increase in
the wetted area. Both these effects would tend to increase the pressure loss
through the bank of splitters and there would also be an increase in splitter
self-noise (section 4) resulting from the higher air speed through the splitter
passages.

Taking all these factors into account, the optimum acoustic design for the
5ft tunnel ought to incorporate banks of nine splitters on each side of the fan.
The splitters should contain 50mm thick acoustic blankets of a material with a
flow resistance of about 7×10^4 mks rayls/m separated by 160 mm air gaps. The
predicted noise attenuation for this configuration (Fig 5) is about 45 dB at
2.5 kHz reducing to less than 10 dB at 10 kHz. As shown in Fig 7, improved
acoustic performance is available when the long tails of the splitters are also
mainly filled with absorbent material.

Further studies suggested that the attenuation bandwidth might be broadened
by deploying complementary banks of splitters with differing physical character-
istics so that their individual attenuation would be tuned to substantially
different centre frequencies. Such a scheme is illustrated in Fig 7 where the
splitters for high-frequency attenuation are far more numerous though smaller in
size than those for low-frequency attenuation. The tunnel configuration limits
the overall splitter length to that of the original splitter design and hence it
is necessary to reduce the length of the low frequency splitters to make room
for the high frequency splitters. For optimum performance in the 5ft tunnel,
the high-frequency splitters should be provided with blanket material with the
very high value of flow resistance of 35×10^4 mks rayls/m. The theory predicts
that this double splitter configuration should reduce background noise by over
20 dB for frequencies between 1.2 and 10 kHz.

3   PRACTICAL MATERIALS FOR SPLITTERS

The previous section outlined an analytical approach for determining the
ideal properties of materials suitable for use in the absorbent blankets of

acoustic splitters, so the next task is to select real materials matching these requirements as closely as possible. Since manufacturers often do not quote the flow resistance of their products, the simple apparatus shown schematically in Fig 8 was assembled so that flow resistance values could be ascertained for various promising materials.

For small values of the air velocity (U m/s) through the absorbent material, the specific flow resistance (R_1 rayls/m) is defined as:

$$R_1 = \Delta P/UT$$

where 'ΔP' is the pressure drop ($N\,m^{-2}$) through a sample of thickness $Tm(= 2t)$. At practical flow rates of 5, 12.5 and 25 mm/s through the 91.5mm diameter tube, measurements were made of the pressure drop through samples with thickness varying between 10 mm and 50 mm depending on the material available. For each sample, the values of the specific flow resistance were sensibly similar at each flow rate and thus it was not necessary to extrapolate the results to zero flow rate. Typical values of specific flow resistance are given below for a variety of materials.

Material		Flow resistance (rayls/m)	Density (kg/m^3)
Polyether foam	(Type A)	0.5×10^4	35
	(Type B)	1.2×10^4	42
Mineral wool	(Type A)	4.4×10^4	178
	(Type B)	8.3×10^4	230
White felt		10.9×10^4	250

From this investigation, it can be seen that the requirement of a flow resistance of 7×10^4 mks rayls/m for the main splitters in the 5ft tunnel would be well matched by using mineral wool (Type B) as the absorbent material. On the other hand, no acceptable material was found which could match the theoretical requirements for the high-frequency splitters (35×10^4 mks rayls/m). The most resistant material tested was the white felt (11×10^4 mks rayls/m) and so this was chosen as the absorber for the high-frequency splitters. Predictions indicate that such a multi-splitter arrangement should give acoustic attenuation in excess of 20 dB for frequencies between 1.2 kHz and 9 kHz (Fig 9).

For health-safety reasons, glass fibre was considered to be an unsuitable material for use as a filler in acoustic splitters for a wind-tunnel, so no

attempt was made to investigate the acoustic efficiency of glass fibre blankets. However, it is worth noting that glass fibres with a diameter of 3 μm packed at 100 kg/m^3 produce a mattress material with a flow resistance of 30×10^4 mks rayls/m (Beranek[4], p 252).

4   TESTS WITH EXPERIMENTAL SPLITTERS

The RAE small-scale 'Jet Research Rig' was modified into an Aero-Acoustic Research Rig with ducted flow (Fig 10) in order to obtain a facility capable of providing experimental verification for the method of predicting the noise attenuation of acoustic splitters in a tunnel flow environment. The modification allows various splitter configurations to be installed in a parallel duct of 380 mm square section so that two types of acoustic experiment can be performed.

Firstly, using 'pink' noise* emitted from a loudspeaker near the inlet of the duct, the noise levels on either side of a bank of splitters can be measured by a pair of ¼ inch microphones (Fig 10). The upstream microphone is merely used as a monitor to check that the noise level from the source remains constant for a range of splitter configurations, and the noise attenuation due to the splitters is determined from the changes in signal strength at the downstream microphone from the values measured in the absence of the splitters.

Alternatively, the facility can be used to investigate the self-noise arising from the flow of air over the splitter surfaces. For this purpose, the loudspeaker and microphones are removed from the duct and noise measurements are made using a ¼ inch microphone with windshield mounted just outside the airstream in the anechoic chamber (Fig 10).

For these experiments, a family of splitters was manufactured using 25mm thick acoustic blankets which could be covered with steel plates perforated in a variety of designs with approximately 40% open area (Fig 11). Provision was also made to fit 12½mm thick acoustic blankets on the side walls of the duct. Predicted values of noise attenuation for mineral-wool splitters separated by air gaps of 38 mm, 70 mm and 165 mm are shown in Fig 12.

Static tests (Fig 13) showed, as expected, that for a fixed length of splitters the noise attenuation *increases* with the number of splitters in the duct (*ie* as the air gap separating the splitters is reduced) and that substantial benefits are available from a judicious choice of material for the acoustic blankets. Thus for an h/t -value of 2.75, attenuation of up to 36 dB is

---

* 'Pink' noise is defined as having equal energy levels in each third-octave bandwidth.

available using mineral wool blankets with a flow resistance of 8.3×10^4 mks rayls/m (Fig 13b), but only 21 dB of attenuation is available using polyether foam blankets for which flow resistance is 0.5×10^4 mks rayls/m (Fig 13a). The peak attenuation, although occurring at about the predicted frequency, is substantially lower than the estimated value (Fig 14a), while at lower frequencies the attenuation is greater than that estimated.

The effect of variations in the length of absorbent material in otherwise solid splitters of constant overall length is demonstrated in Fig 14b. Over the frequency range from 1 kHz to 10 kHz, the noise attenuation increases linearly with absorber length for values of $\ell/t > 12$ though there would appear to be a greater dependence on length for shorter sections of acoustic treatment. Covering the absorbent material with perforated plates of 40% open area gives only a small reduction in the noise attenuation (Fig 14a) though when this perforate is faced with aircraft linen (to reduce splitter 'self-noise') there is a significant reduction in the acoustic performance of the splitters.

A few tests have been made with a specimen of a splitter design suitable to represent the high-frequency splitters for the 5ft tunnel modification (Fig 15). In contrast with the foregoing low-frequency splitter comparison, the performance of these high-frequency splitters is similar to that predicted by the theory of Cremer.

The self-noise generated by the airstream passing over the various types of perforate pattern of the splitter covers is shown in Fig 16. In general, the covers with longitudinal slots produce the highest noise levels; to a large extent, this is a result of reduced rigidity of the cover plates which allows them to distort into the stream. At low-frequencies the circular hole pattern creates the least noise, but there is a constant Strouhal frequency at which they produce their own signature some 10 dB above the background noise level of the facility. This signature could be substantially reduced by covering the splitters with aircraft linen (Fig 16) but, as mentioned earlier, this would result in reduced acoustic performance. A more satisfactory solution is to face the splitters with calico but this must be firmly stuck to the metal throughout its area, so that it was found to be necessary to increase the size of the holes in the perforate to at least 2.5 mm diameter in order to avoid the possibility of clogging these holes with glue. Such treatment reduces splitter self-noise (Fig 17) but does result in impaired noise attenuation at frequencies above 2 kHz (Fig 18). Further investigations are desirable to improve the design and attachment of

splitter covers to retain optimum noise attenuation for minimum splitter self-noise in an airstream.

5   RECOMMENDATIONS FOR DESIGN OF SPLITTERS FOR THE 5ft AND 24FT TUNNELS AT RAE

From consideration of the physical size of typical test vehicles in the 5ft wind-tunnel, it could be deduced that, ideally, this facility needs good acoustic properties at frequencies above 1 kHz to give adequate model-scale representation for aero-acoustic research. To meet this requirement, banks of low-frequency and high-frequency splitters should be installed on each side of the repositioned fan, with their peak attenuations centred on frequencies of about 2 kHz and 7.5 kHz respectively. To achieve this aim, the 50mm thick low-frequency splitters should contain blankets of mineral wool with a flow resistance of 8×10^4 rayls/m separated by air-gaps of 160 mm. Felt with a flow resistance of 11×10^4 rayls/m should be a suitable material for the 12mm thick high-frequency splitters which should be separated by air-gaps of 60 to 65 mm.

Similar model representation in the larger 24ft tunnel would require adequate acoustic properties at frequencies as low as 200 Hz. Consequently, in this facility, the splitter design should be centred on maximum attenuation at 400 Hz and 1500 Hz for the low-frequency and high-frequency splitters respectively. Thus the 250mm thick low-frequency splitters should be filled with a blanket with a flow resistance of about 1.5×10^4 rayls/m (polyether foam Type B has a flow resistance of 1.2×10^4 rayls/m) with air gaps of 760 mm between splitters, while the above mentioned mineral wool would provide 60mm thick blanket material for the high frequency splitters which should be separated by air gaps of 300 mm.

In all cases, the splitters must be of a low-drag profile, for example with semi-elliptic noses and tapered tails, while the absorbent material should be covered with a circular-hole metal perforate of some 40% open area faced with calico in order that the splitter self-noise be kept to a minimum. Further research into the possibility of reducing 'self-noise' is desirable as this remains a problem in the relatively high-speed sections of wind-tunnel circuits where it is necessary to install banks of splitters.

6   CONCLUDING REMARKS

Subsequent to the work discussed in this Memorandum, the 5ft tunnel was modified to become the 1.5 metre acoustic tunnel which is described in Ref 2. The acoustic splitters were designed using the techniques described in this Memorandum. At zero air speed, the noise attenuation through the acoustic splitters agreed well with estimates based on this exploratory work, while, as

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expected, the effects of self-noise at high air speeds substantially reduced their nett acoustic performance. Indeed, the self-noise generated by the high-frequency splitters in the high-speed collector section of the tunnel was so severe that they gave no overall benefit and were eventually removed from the circuit[2]. Even so, the new '1.5 metre tunnel' facility is at least 15 dB quieter than the old 5ft tunnel arrangement over the frequency range from 0.2 kHz to 5 kHz, at the same air speed.

LIST OF SYMBOLS

h	(mm)	half air gap between splitters
ℓ	(mm)	length of acoustic treatment in splitters
t	(mm)	half thickness of splitters
U	(m/s)	velocity of airstream
ΔP	(N m^{-2})	pressure drop through porous materials
R_1	(mks rayls/m)	flow resistance (see Fig 8)

REFERENCES

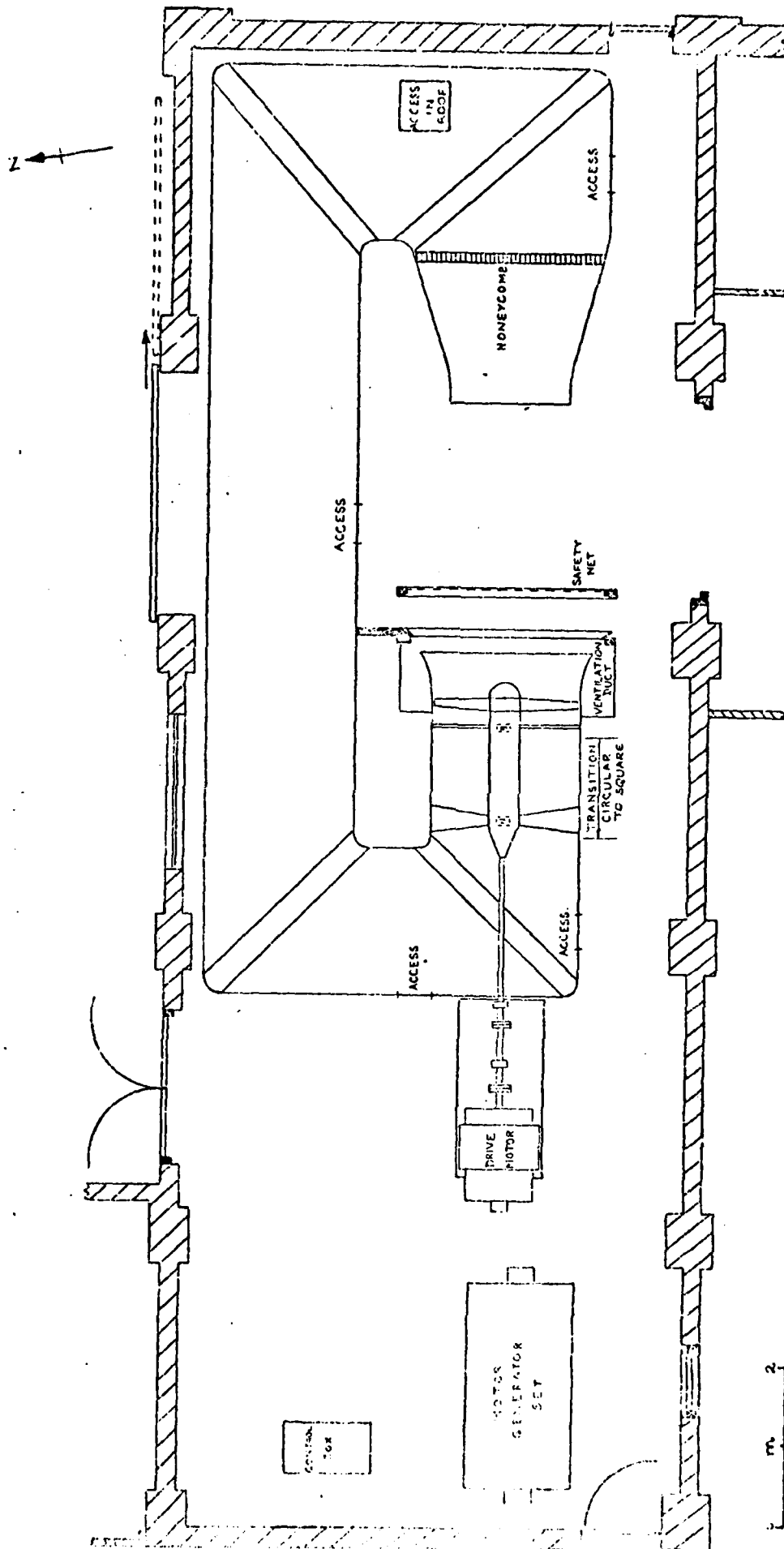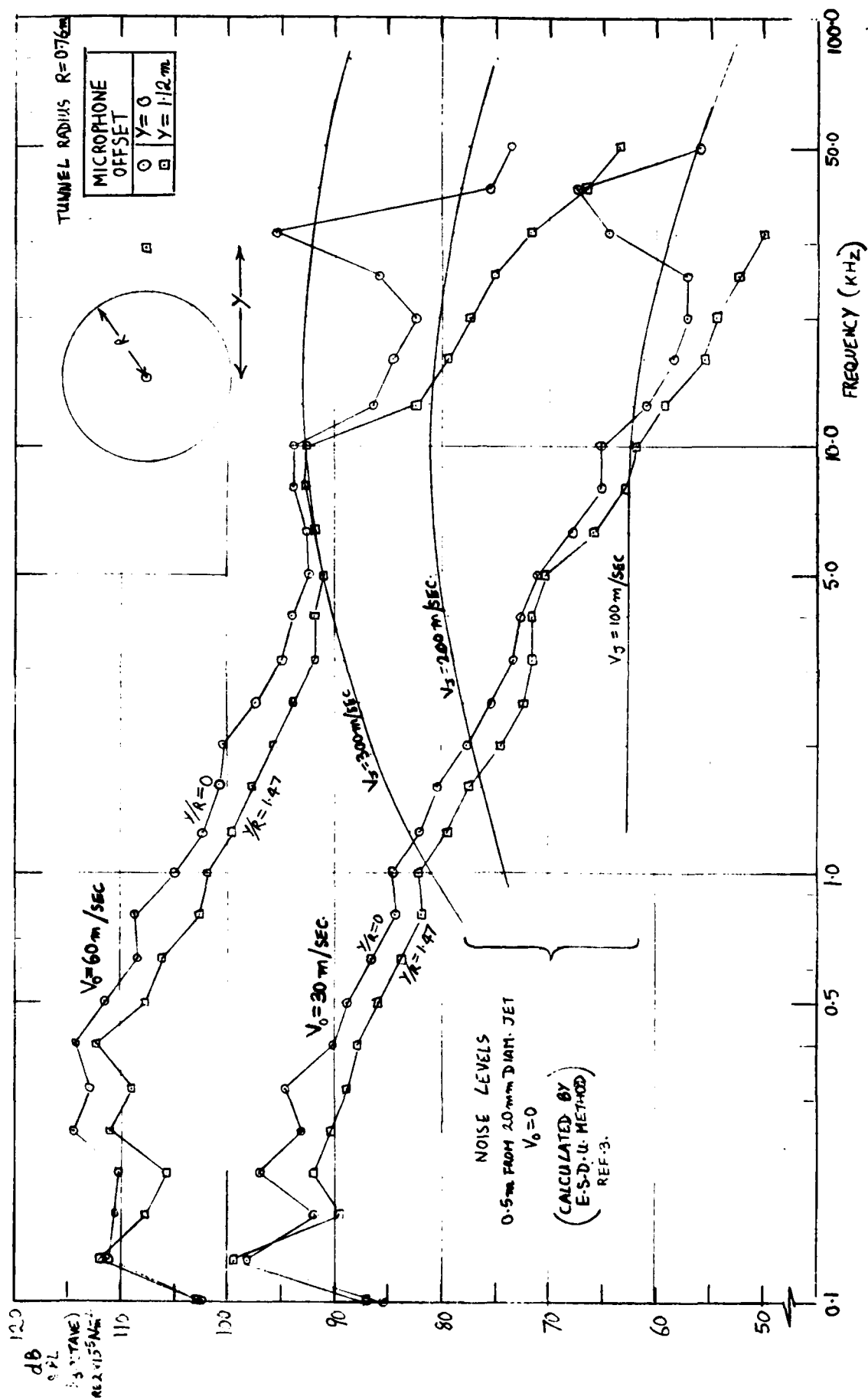| No.	Author	Title, etc
1	J. Williams T.B. Owen A. Spence	Proposed improvements to the RAE 24ft tunnel facility for noise, helicopter and V/STOL model experiments. RAE Technical Memorandum Aero 1591 (1974)
2	W.J.G. Trebble	The acoustic characteristics of the RAE 1.5m wind-tunnel RAE Technical Report 79002 (1979)
3	-	Estimation of subsonic far-field jet-mixing noise. Engineering Sciences Data Unit. Item No.74002 (1973)
4	L.L. Beranek	Noise and control. Chapter 15. McGraw Hill Book Co. (1971)
5	M.E. Delaney E.N. Bazley	Acoustical characteristics of fibrous absorbent materials. NPL Aero Report Ac37 (1969)

Fig 1   Original circuit of 5ft wind tunnel

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Fig 2

Fig 2   Noise levels in original 5ft wind tunnel

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Fig 3

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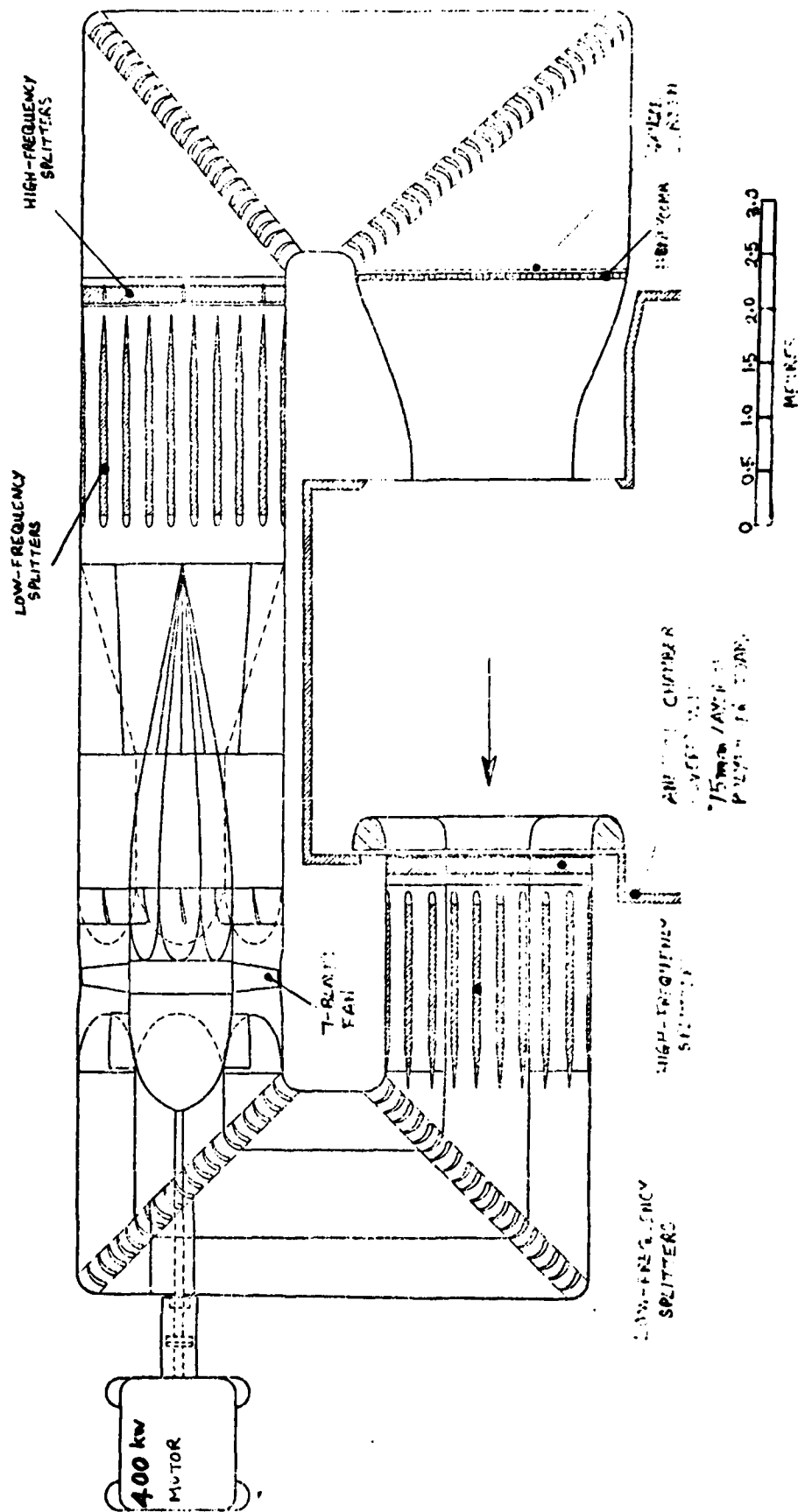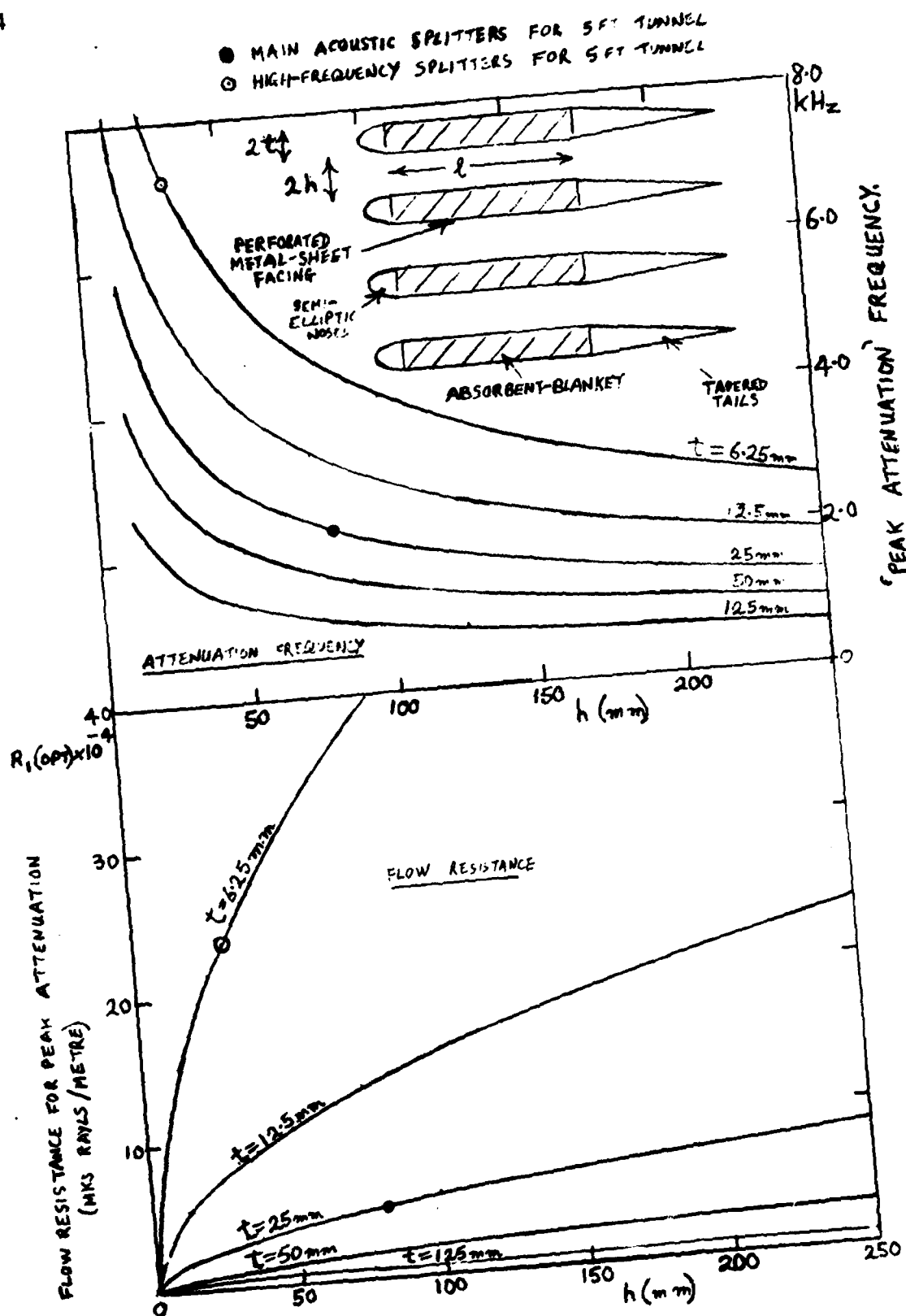Fig 3   Modified tunnel circuit for acoustic research

Fig 4

Fig 4   Effect of splitter geometry on frequency of
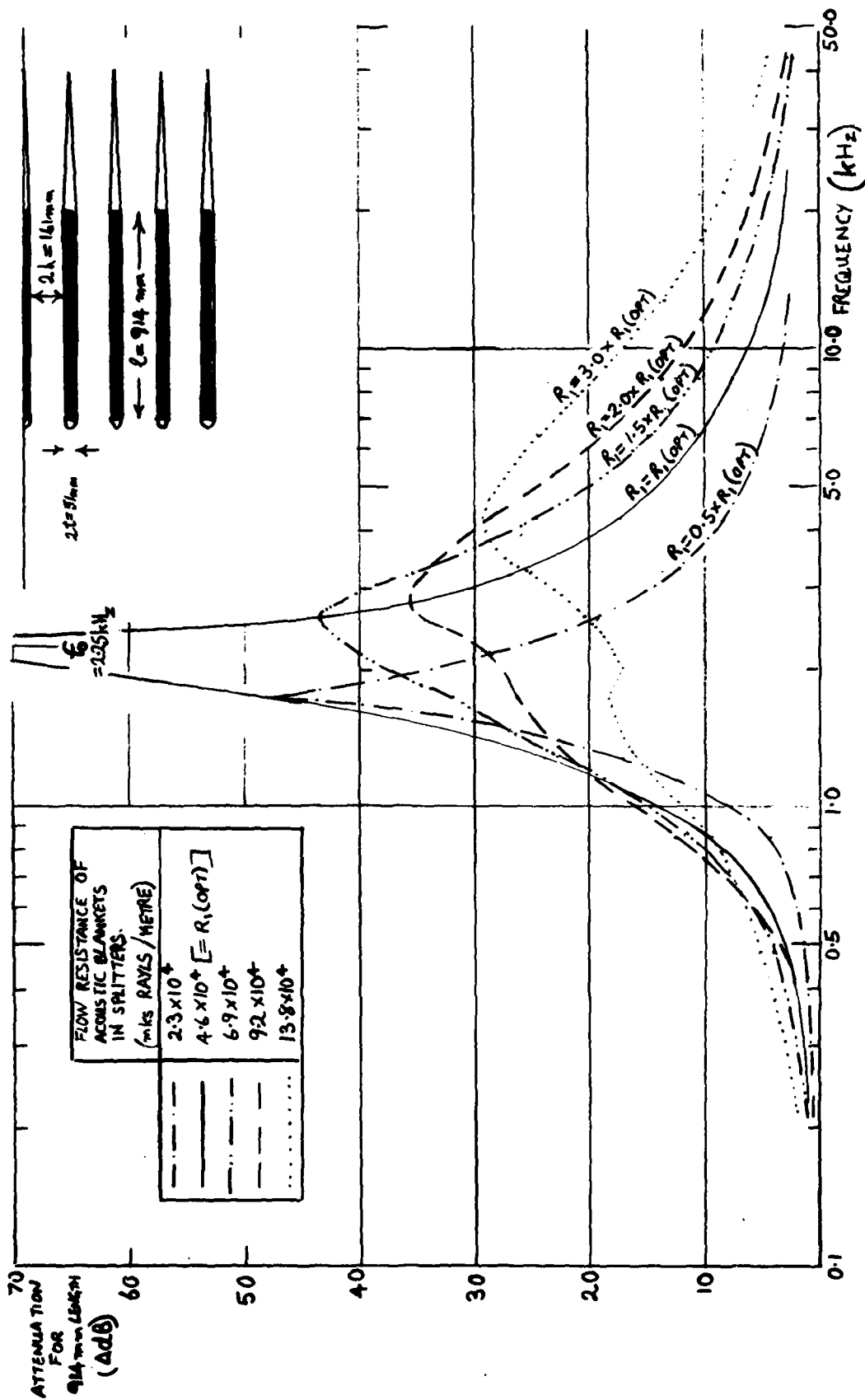peak attenuation (predicted)

Fig 5

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Fig 5   Predicted noise attenuation with acoustic splitters in 5ft tunnel.
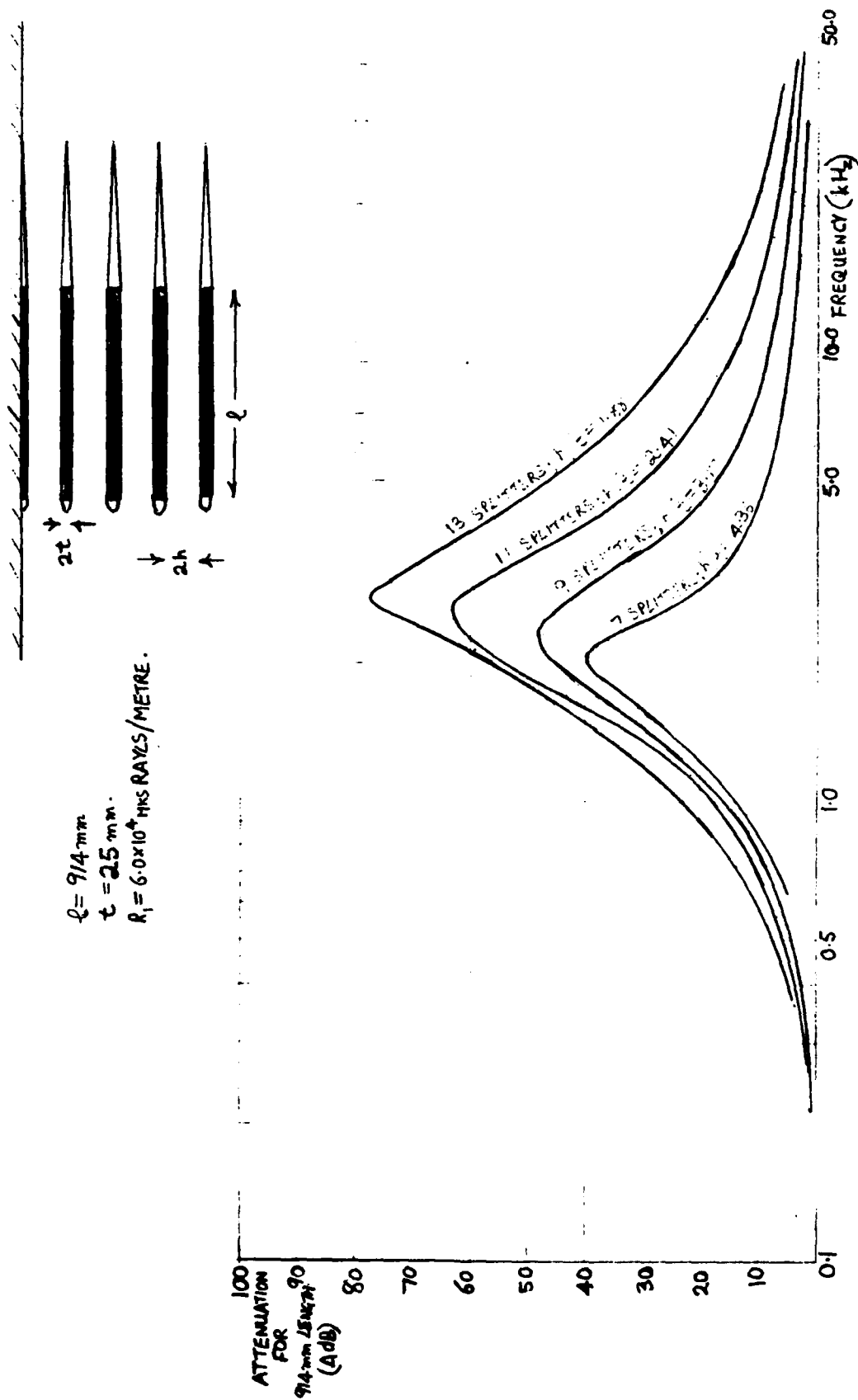Effect of flow resistance of acoustic blanket

Fig 6

Fig 6   Effect of variation in width of air-gap on predicted performance of splitters
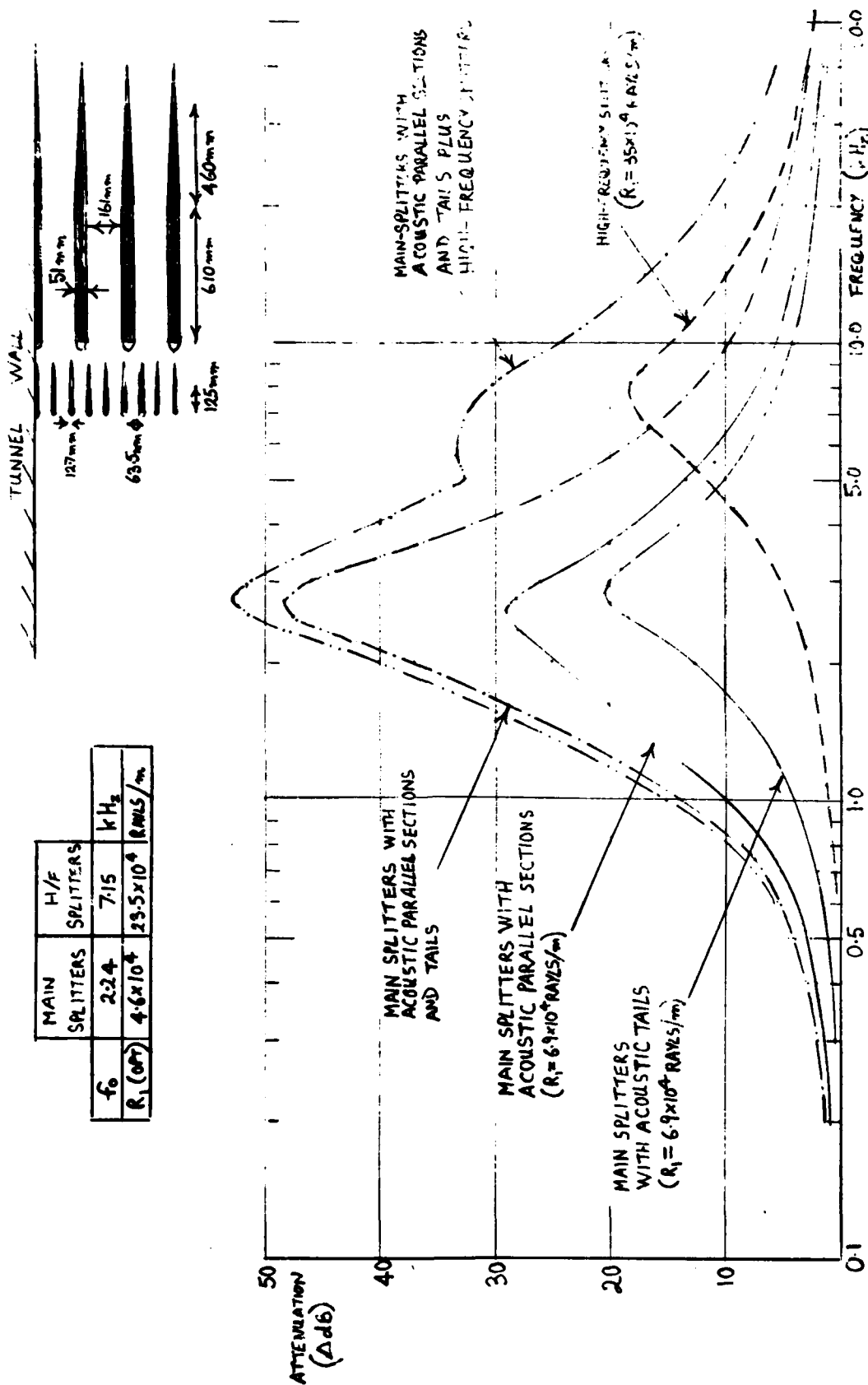
Fig 7

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	MAIN SPLITTERS	H/F SPLITTERS	kHz
f_0	2·24	7·15	kHz
R_1 (opt)	4·6×10⁴	23·5×10⁴	RAYLS/m

TUNNEL WALL

51 mm
127 mm
161 mm
63·5 mm ⌀
125 mm
610 mm
460 mm

MAIN SPLITTERS WITH ACOUSTIC PARALLEL SECTIONS AND TAILS

MAIN SPLITTERS WITH ACOUSTIC PARALLEL SECTIONS ($R_1 = 6·9×10⁴$ RAYLS/m)

MAIN SPLITTERS WITH ACOUSTIC TAILS ($R_1 = 6·9×10⁴$ RAYLS/m)

MAIN-SPLITTERS WITH ACOUSTIC PARALLEL SECTIONS AND TAILS PLUS HIGH-FREQUENCY SPLITTERS

HIGH-FREQUENCY SPLITTERS ($R_1 = 35×10⁴$ RAYLS/m)

ATTENUATION (ΔdB)

50
40
30
20
10

0·1   0·5   1·0   5·0   10·0   FREQUENCY (kHz)

Fig 7   Predicted noise attenuation with low-frequency and high-frequency splitters in 5ft tunnel using ideal materials
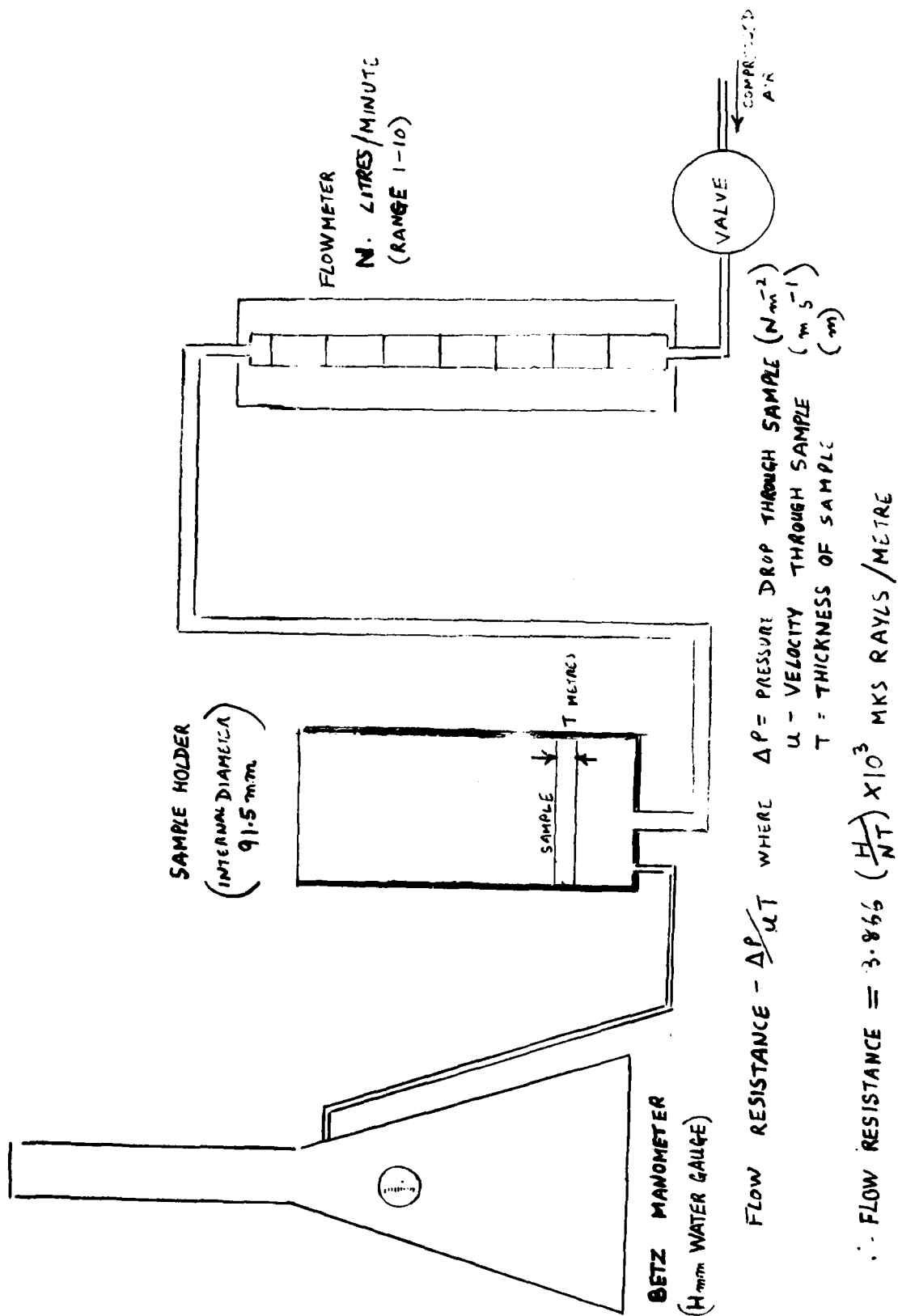
Fig 8

FLOWMETER
N. LITRES/MINUTE
(RANGE 1-10)

VALVE

COMPRESSED AIR

SAMPLE HOLDER
(INTERNAL DIAMETER
91·5 mm)

SAMPLE

T METRES

BETZ MANOMETER
(H mm WATER GAUGE)

FLOW RESISTANCE = $\frac{\Delta P}{u T}$ WHERE ΔP = PRESSURE DROP THROUGH SAMPLE ($N\,m^{-2}$)

u = VELOCITY THROUGH SAMPLE ($m\,s^{-1}$)

T = THICKNESS OF SAMPLE (m)

∴ FLOW RESISTANCE = $3.866 \left(\frac{H}{NT}\right) \times 10^{3}$ MKS RAYLS/METRE

Fig 8   Apparatus for measurement of flow resistance
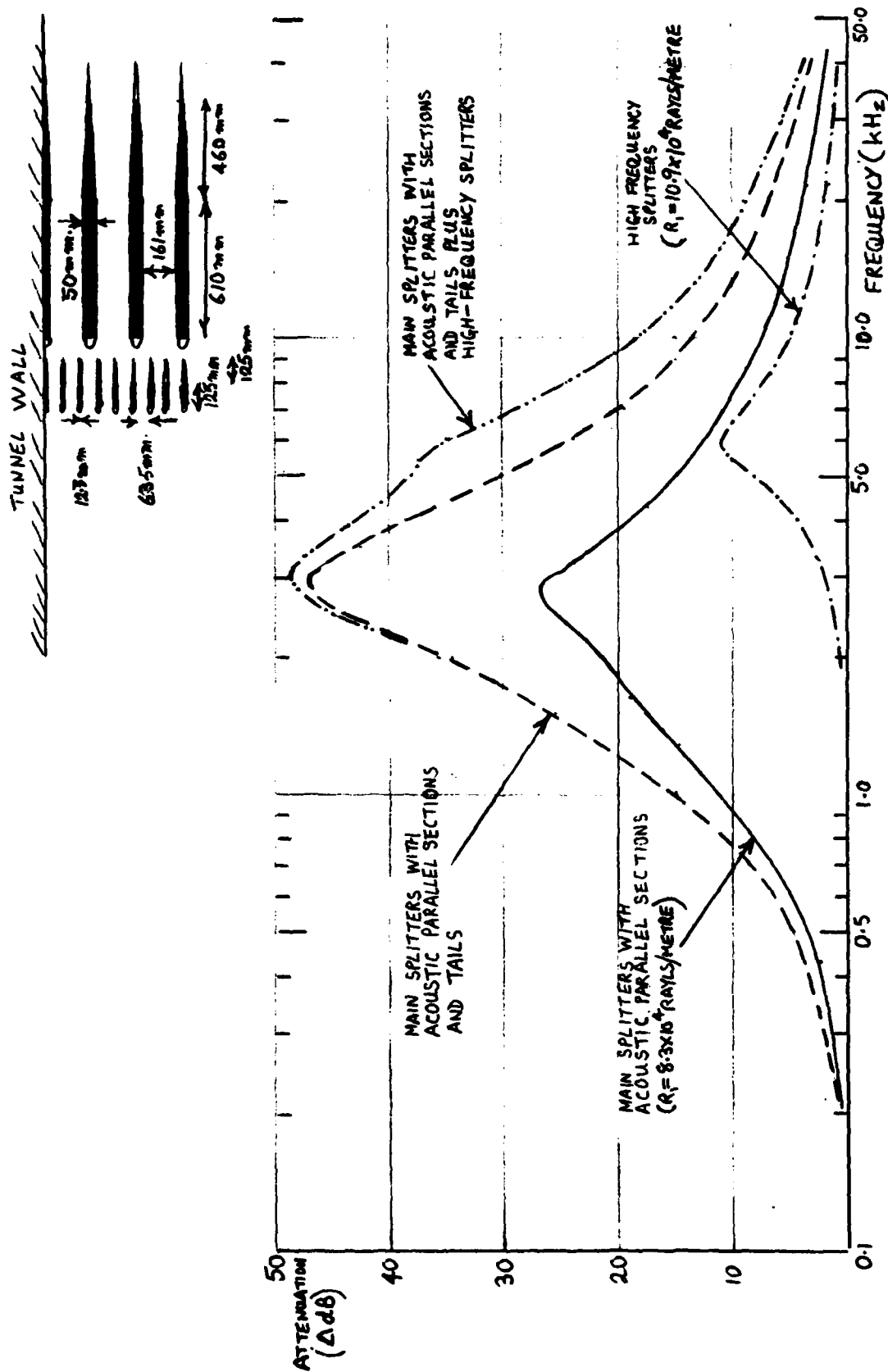
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Fig 9

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Fig 9   Predicted noise attenuation with low-frequency and high-frequency splitters in 5ft tunnel using available materials
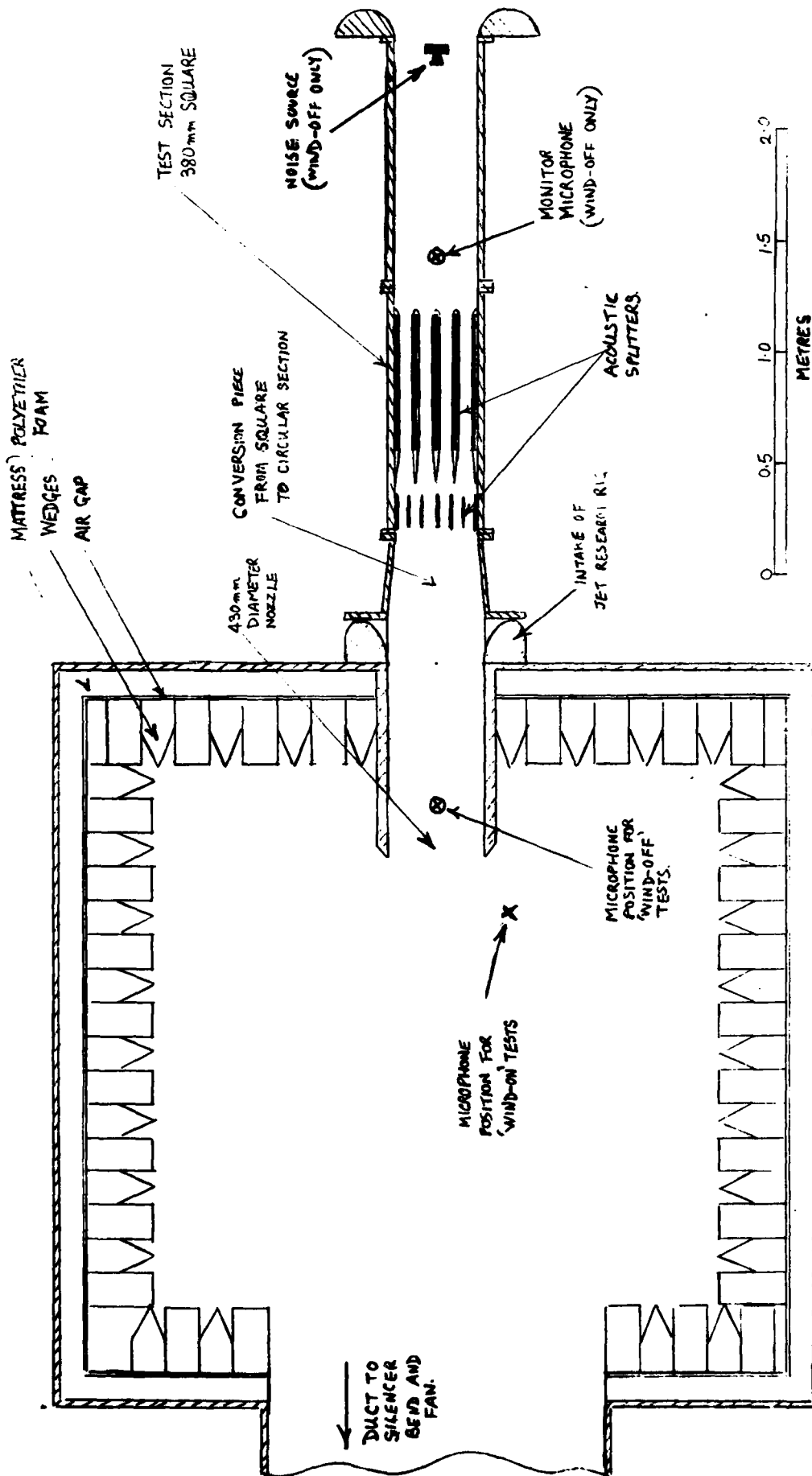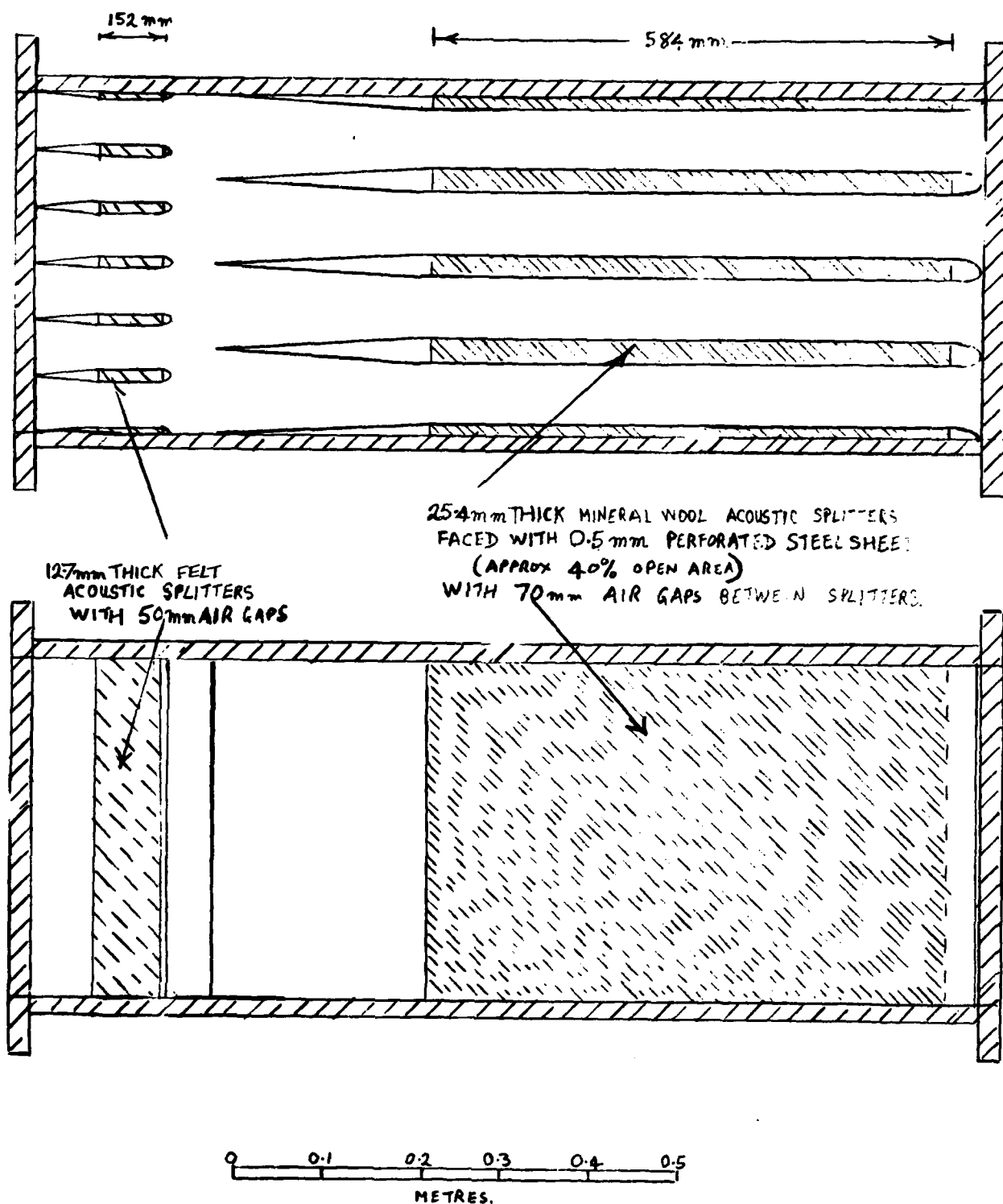
Fig 10

Fig 10   Acoustic research rig

Fig 11

152 mm

584 mm

254 mm THICK MINERAL WOOL ACOUSTIC SPLITTERS
FACED WITH 0.5 mm PERFORATED STEEL SHEET
(APPROX 40% OPEN AREA)
WITH 70 mm AIR GAPS BETWEEN SPLITTERS.

127 mm THICK FELT
ACOUSTIC SPLITTERS
WITH 50 mm AIR GAPS

0   0.1   0.2   0.3   0.4   0.5

METRES.

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Fig 11   Installation of splitters in acoustic research rig

Fig 12
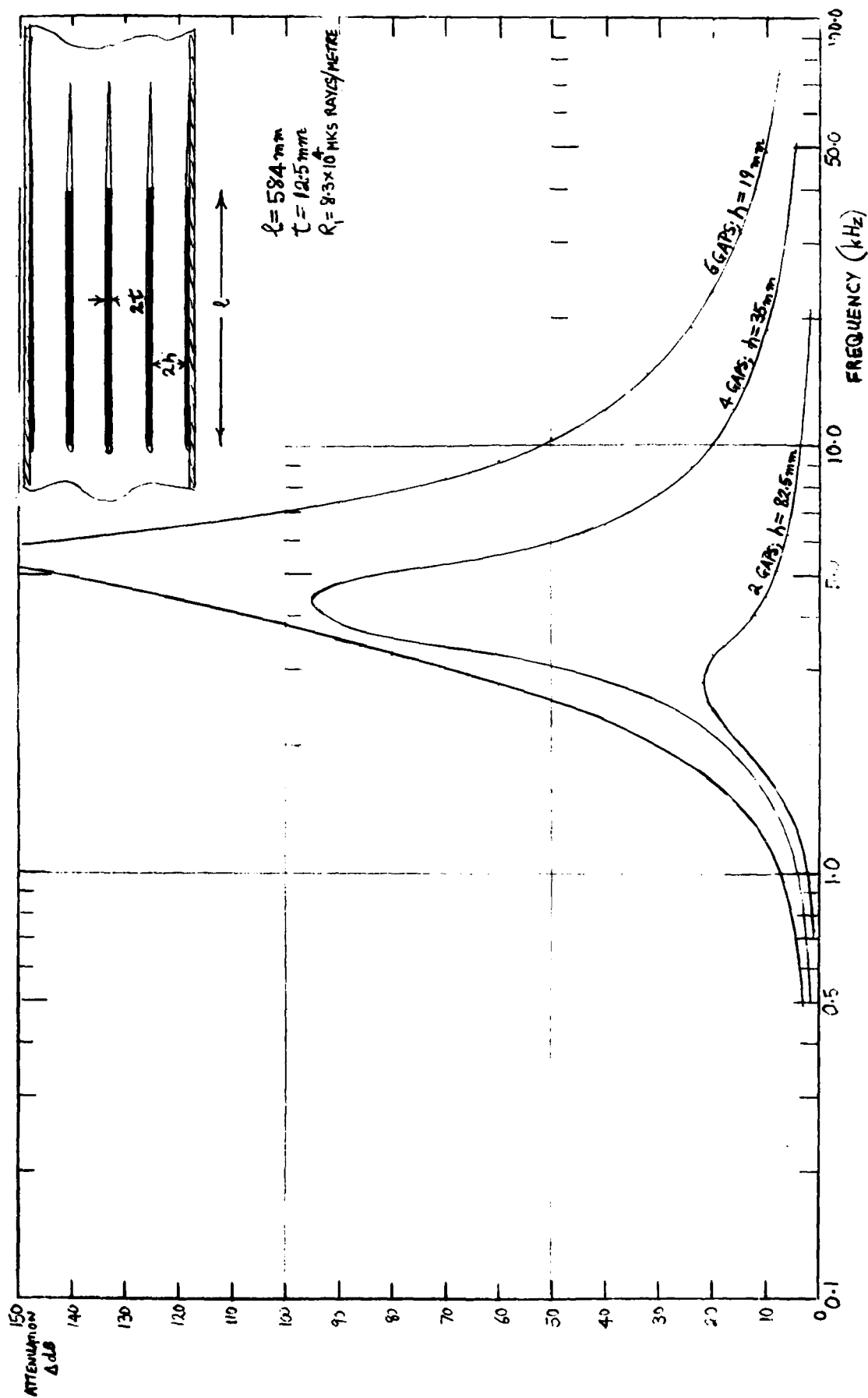
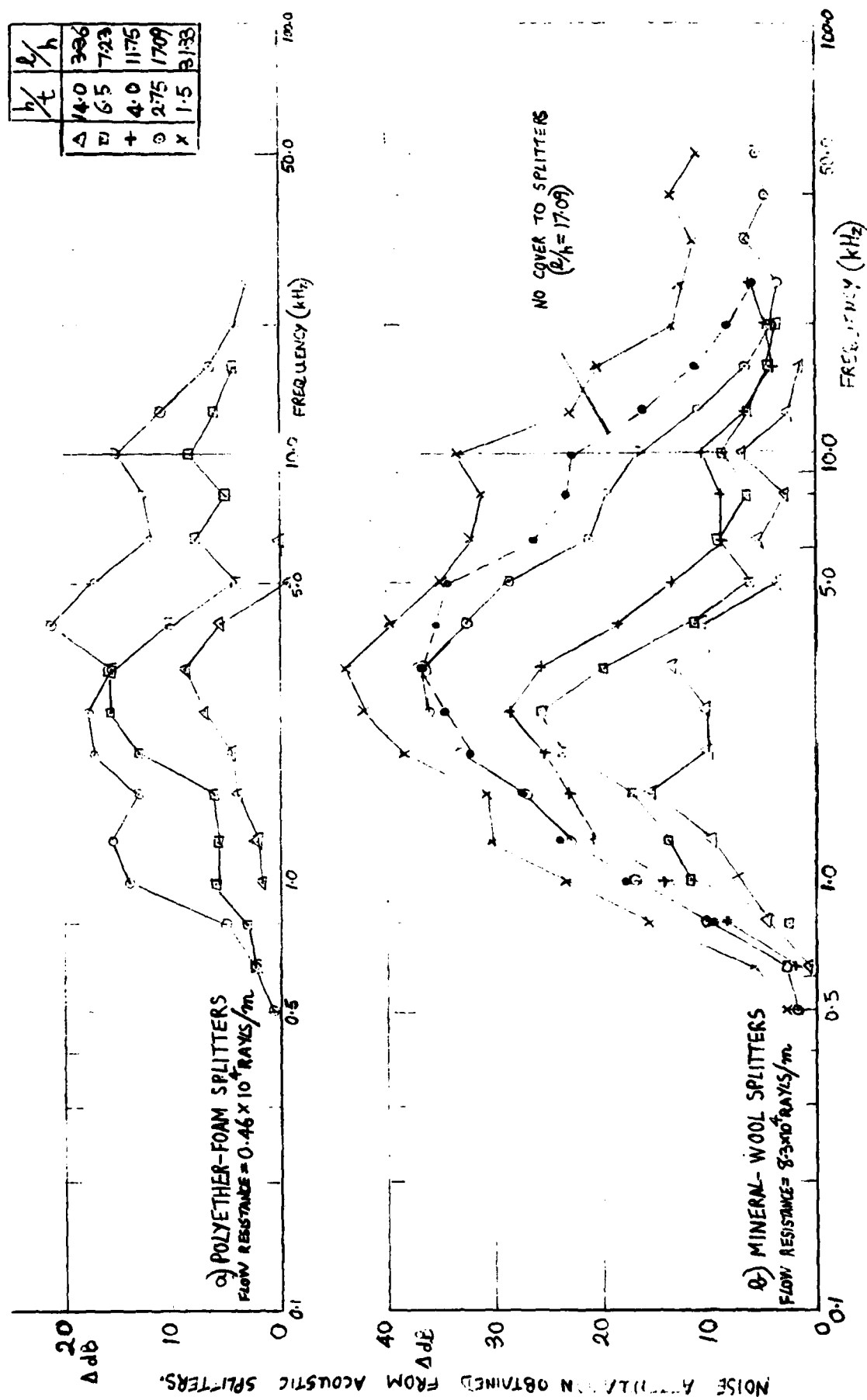Fig 12   Predicted noise attenuation for splitters in acoustic research rig

Fig 13

	h/t	ℓ/h
△	14.0	3.36
□	6.5	7.23
+	4.0	11.75
⊙	2.75	17.09
×	1.5	31.33

a) POLYETHER-FOAM SPLITTERS
FLOW RESISTANCE = 0.46 × 10⁴ RAYLS/m

b) MINERAL-WOOL SPLITTERS
FLOW RESISTANCE = 8.3×10⁴ RAYLS/m

NO COVER TO SPLITTERS
(ℓ/h = 17.09)

FREQUENCY (kHz)

NOISE ATTENUATION OBTAINED FROM ACOUSTIC SPLITTERS, ΔdB
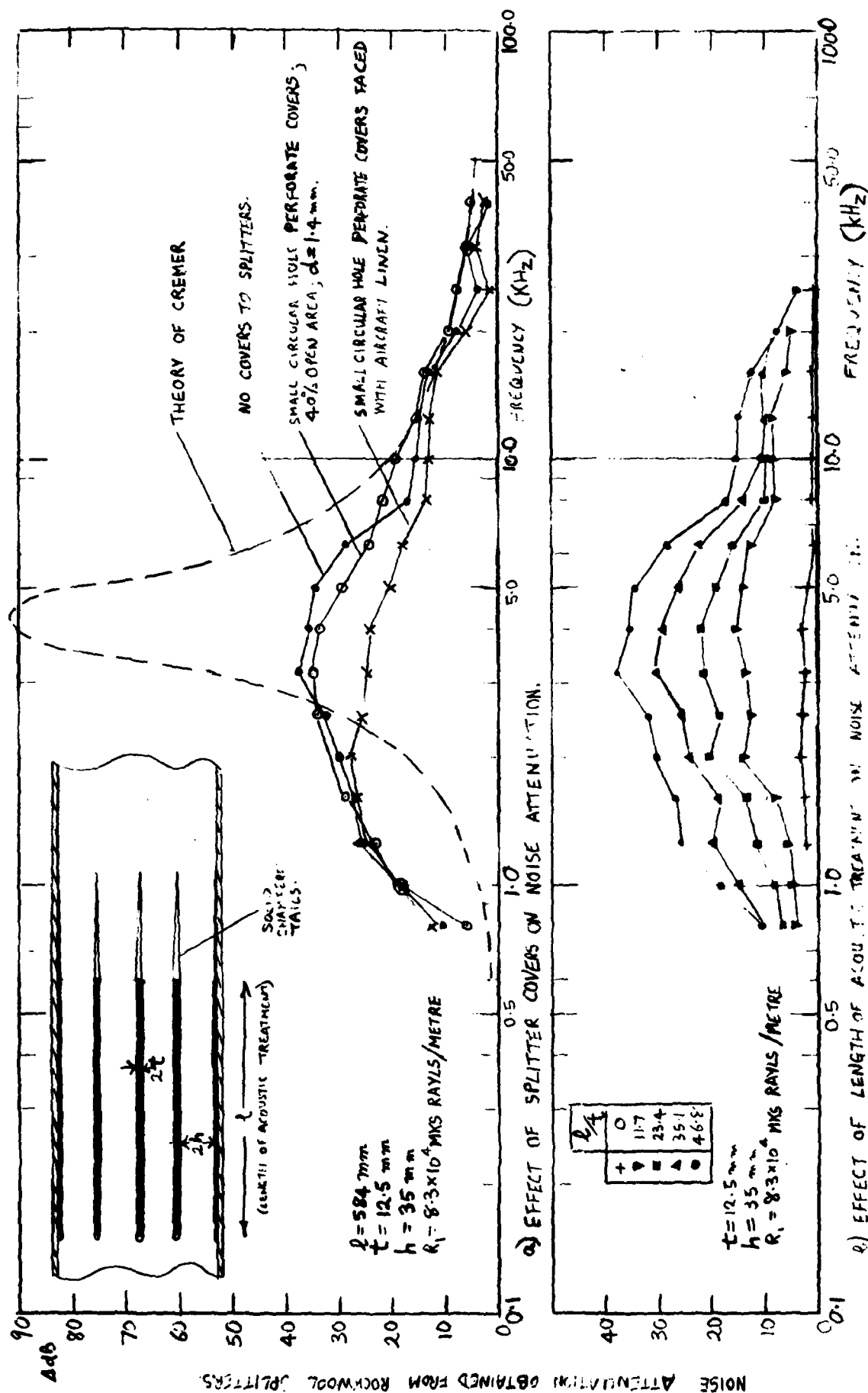
Fig 13   Effects of variations in air-gaps and flow-resistance on noise attenuation of splitters in the acoustic research rig

Fig 14

Fig 14   Noise attenuation produced by mineral-wool splitters in acoustic rig

Fig 15

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FLOW RESISTANCE = 10·9×10⁴ MKS RAYLS/m

2h = 51 mm

2τ = 127 mm

ℓ = 152 mm

THEORY OF CREMER

MEASURED ATTENUATION

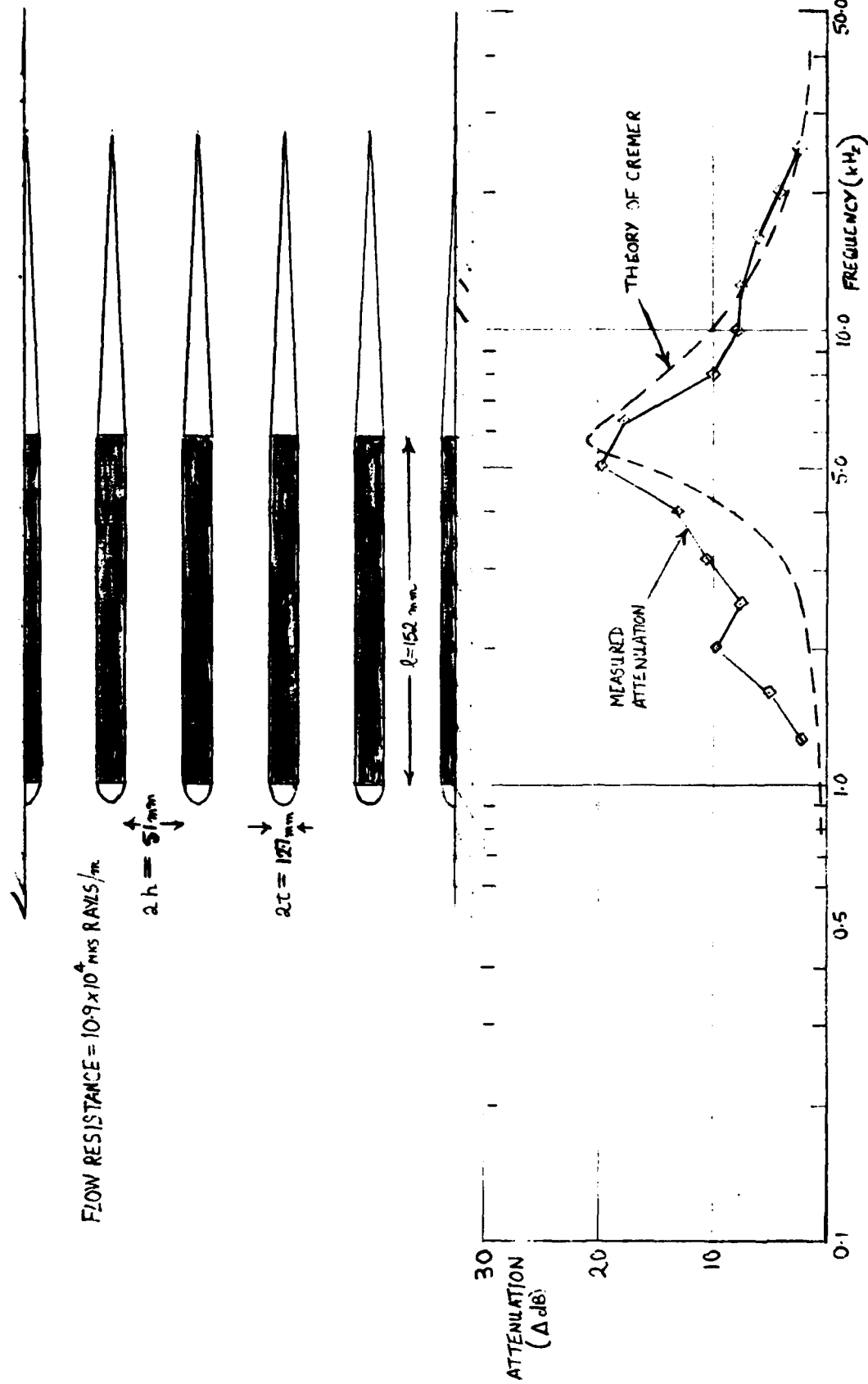FREQUENCY (kHz)

ATTENUATION (Δ dB)

Fig 15   Noise attenuation produced by felt splitters in acoustic research rig
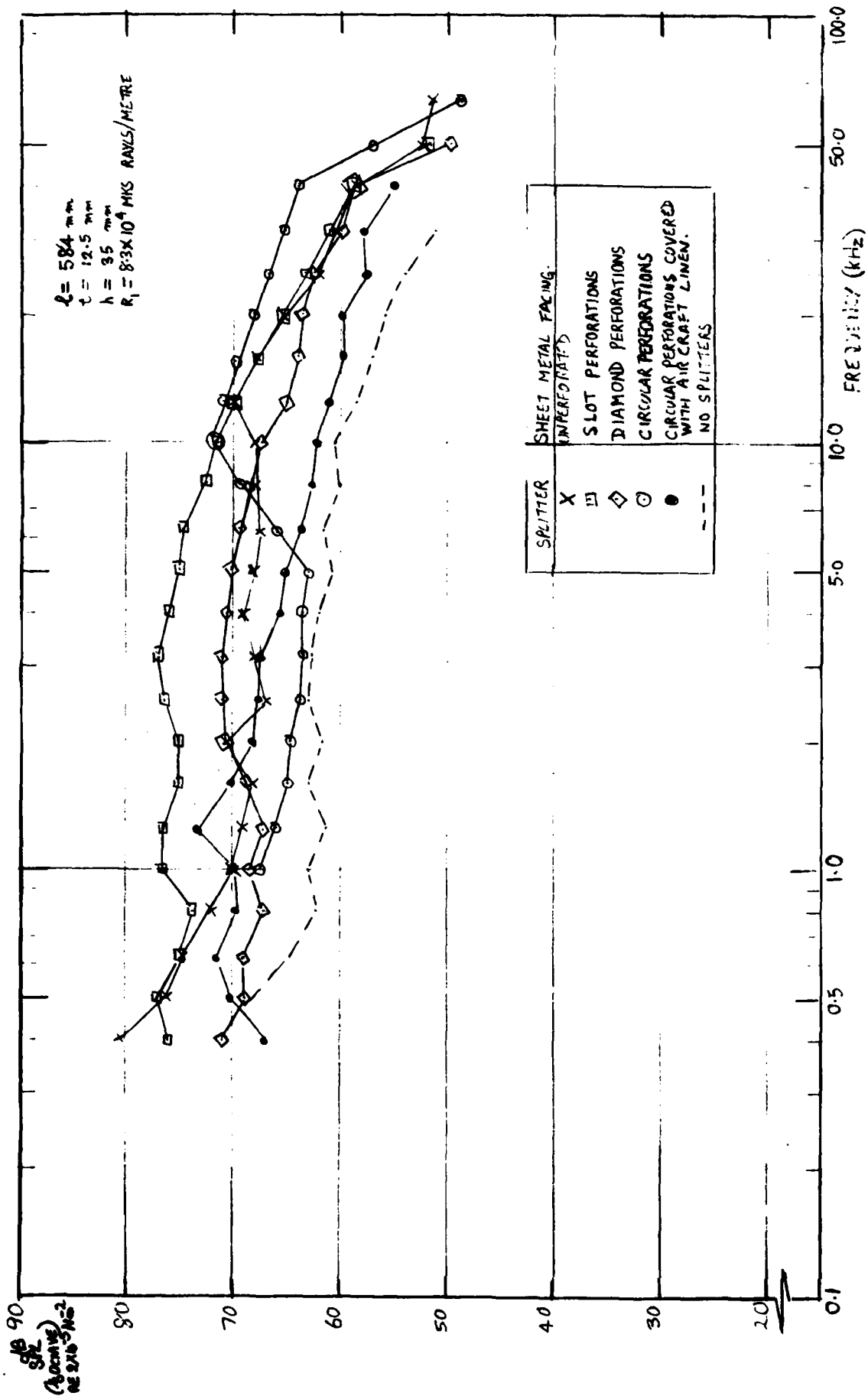
Fig 16

Fig 16　Effect of perforation geometry on 'self-noise' of splitters
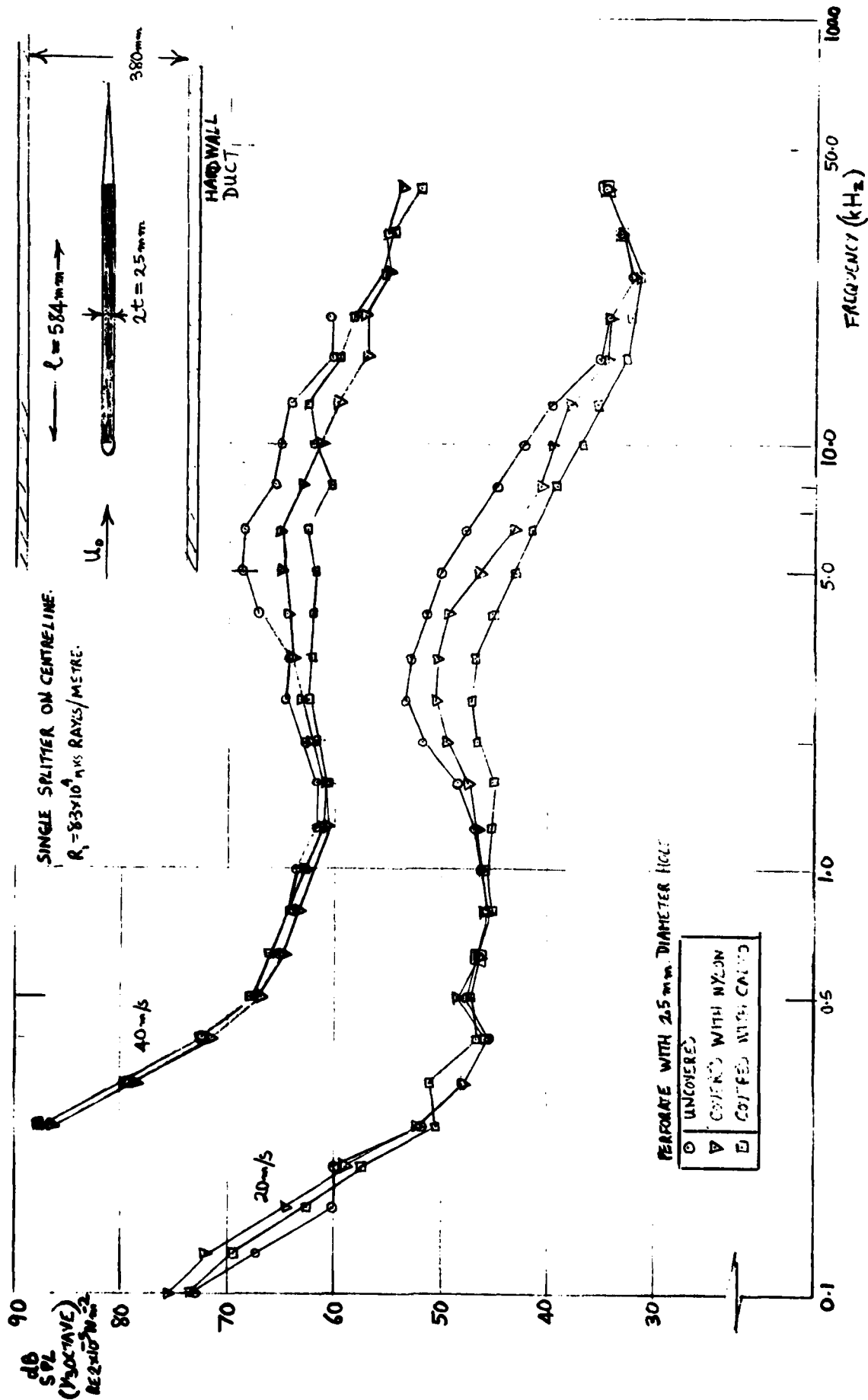　　　　$U_0 = 40$ m/s

Fig 17

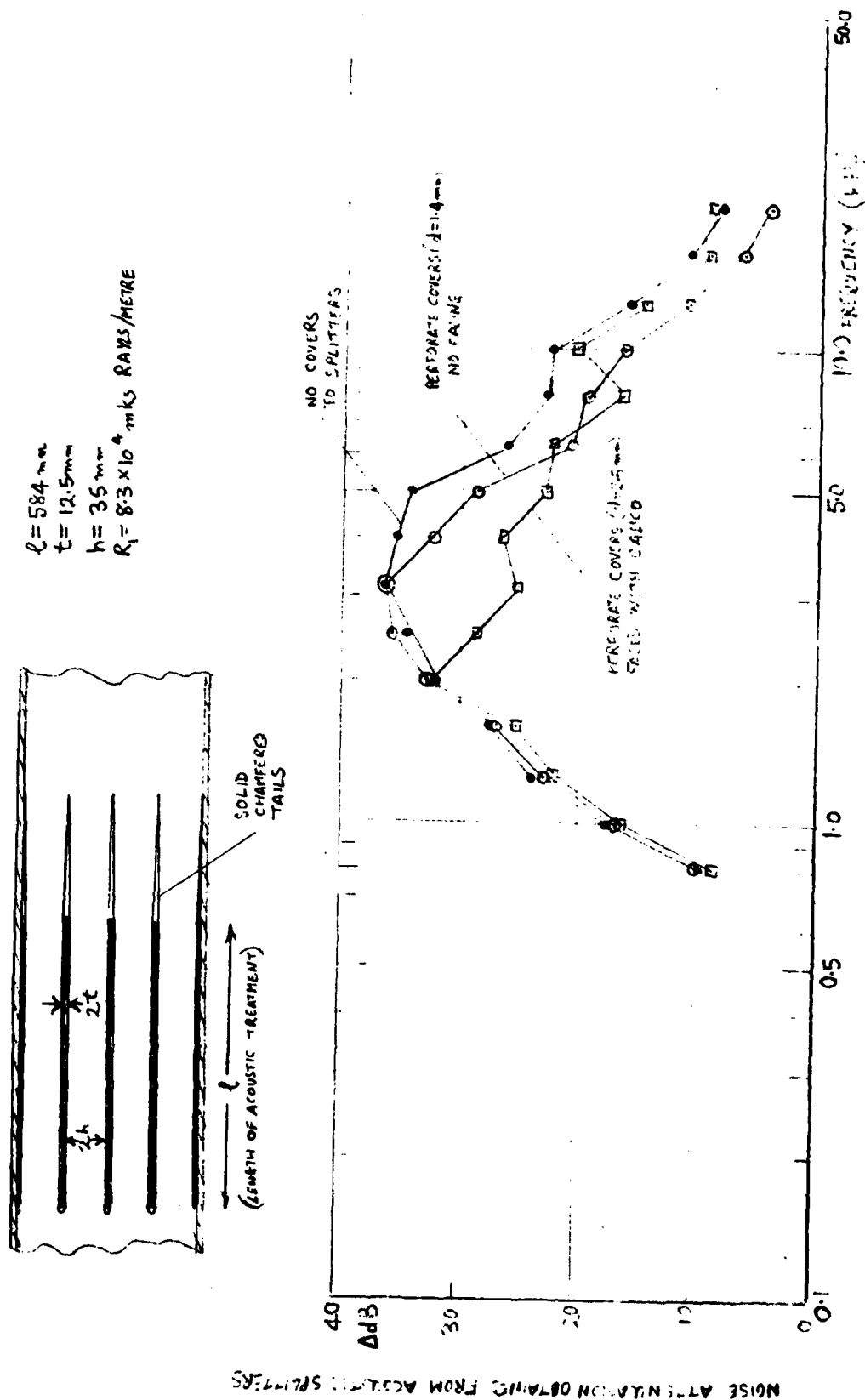Fig 17   Effect of cloth cover in reducing splitter 'self-noise' with flow along duct

Fig 18

Fig 18   Degradation of acoustic performance of splitters caused by protective covers and facings

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REPORT DOCUMENTATION PAGE

Overall security classification of this page

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Acoustic blanket. Acoustic splitters. Wind tunnel.

17. Abstract

This Memorandum discusses the choice of geometry and materials for acoustic splitters in wind tunnels, with particular reference to the requirements for modifying the 5ft and 24ft tunnels at RAE. The optimum theoretical design of acoustic splitters is considered first and then practical materials to match the requirements are chosen. Experimental investigations at small scale in an aero-acoustic research rig with ducted flow are described. Attention is drawn to the need for the splitters to have a good aerodynamic profile and to the problems associated with the self-noise of the splitters when they are installed in high-speed sections of the tunnel circuit.